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RESEARCH MEMORANDUM

TEST-STAND INVESTIGATION OF A RECTANGULAR RAM-JET ENGINE

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RESEARCH MEMORANDUM

TEST-STAND INVESTIGATION OF A RECTANGULAR RAM-JET ENGINE

By Dugald O. Black and Wesley E. Messing

SUMMARY

A test-stand investigation has been conducted on a rectangular ram-jet engine designed for installation in an aircraft wing. The combustion efficiency was determined for a fuel-air-ratio range of 0.025 to 0.083 and for a range of combustion-chamber inlet velocities from 61 to 124 feet per second.

The engine operated without excessive engine noise or vibration over the entire range of operating conditions. The combustion efficiency was approximately 80 percent at fuel-air ratios from 0.060 to 0.068 over a range of combustion-chamber inlet velocities from 64 to 83 feet per second. In general, a change in fuel-air ratio above or below stoichiometric mixture resulted in a decrease in combustion efficiency. The only noticeable effect of combustion-chamber inlet velocity on combustion efficiency occurred at fuel-air ratios less than 0.043, at which condition an increase in combustion-chamber inlet velocity resulted in an increase in combustion efficiency for a given fuel-air ratio. Orsat analysis of the exhaust gases for measured fuel-air ratios of 0.065 and 0.042 indicated fairly uniform fuel-air-ratio distribution across the exit of the engine.

INTRODUCTION

As part of a research program on ram-jet engines, test-stand and flight investigations at subsonic velocities are being conducted at the NACA Cleveland laboratory to determine the performance and operational characteristics of a rectangular ram-jet engine designed for installation in an aircraft wing.

During the test-stand investigation reported herein, combustion efficiency was determined for fuel-air-ratios from 0.025 to 0.083 and combustion-chamber inlet velocities from 61 to 124 feet per second. Exhaust-gas analyses were made at various stations across the exit of the ram-jet engine to determine the fuel-air-ratio distribution. Because of the comparatively low inlet-air velocities available, only a limited amount of information on blow-out and ignition limits were obtained. A flight investigation on a rectangular ram-jet engine installed in a short-span wing mounted beneath the fuselage of a twin-engine fighter-type airplane will extend the investigation to higher combustion-chamber velocities and altitudes from sea level to 30,000 feet.

APPARATUS AND PROCEDURE

The rectangular ram-jet engine (figs. 1 and 2) consists of an inlet diffuser, fuel-spray bar, spark plug and ignition cone, flame holder, and combustion chamber. The diffuser inlet is of a rectangular cross section with a 12° total diffuser angle between the top and the bottom walls. One of the parallel side walls contained a transparent section upstream of the flame holder, which permitted visual observation of the fuel spray and combustion. The combustion chamber was cooled by circulating the fuel through 1/4-inch copper tubing clamped to the wall of the combustion chamber. In addition to cooling the combustion chamber, this system preheated the fuel. The fuel pressure loss in the 1/4-inch tubing was kept low by using a number of separate flow paths instead of one continuous path.

The fuel-spray bar consisted of eight fixed-area spray nozzles evenly spaced along the horizontal center line of the diffuser. Each nozzle had a rated flow of 40 gallons of fuel per hour at a fuel pressure of 100 pounds per square inch and discharged downstream in a 60° cone. The flame holder, consisting of horizontal and vertical V-shaped gutters, was fabricated from 0.064-inch Inconel. The measured pressure-drop coefficient without combustion $\frac{\Delta p}{q}$ for this flame holder was 1.40, (where Δp, pressure drop in in. water across flame holder; q, impact pressure in in. water directly in front of flame holder). Burning was initiated by a spark plug installed in an ignition cone mounted in front of the flame holder. No auxiliary fuel was introduced in the ignition cone.

Air was supplied to the engine by a 500-horsepower, variable-speed, axial-flow blower capable of supplying a pressure rise of 45 inches of water. The engine exhausted to the atmosphere. The fuel used for these tests was AN-F-22 (62 octane).

Data were obtained over a range of fuel-air ratios from 0.025 to 0.083 and combustion-chamber inlet velocities (at the flame holder) from 61 to 124 feet per second.

Engine air flow was calculated from the total and the static pressures measured at the diffuser inlet with three rakes and six static wall orifices and from the inlet-air temperatures indicated by a resistance-bulb thermometer. The ambient-air pressure was measured by a recording barometer. The total pressures of the exhaust gases were measured by means of a water-cooled Inconel rake. Static-pressure surveys made at the exit of the engine indicated that the static pressure was equal to the ambient pressure. Pressure data were obtained simultaneously by photographing a multiple-tube manometer board. Fuel flow was measured with a rotameter. Orsat analyses were made of the oxidized exhaust gases to determine the fuel-air ratio at various points across the exit of the ram-jet engine.

The exhaust-gas temperature at the exit of the ram jet was calculated from the measured gas flow and pressure measurements at the exit of the combustion chamber in accordance with the method outlined in reference 1. The combustion efficiency was determined in accordance with the following equation:

$$\eta_b = \frac{H_g - H_a}{f/a\ (h)} 100 \qquad (1)$$

where

η_b combustion efficiency, percent

H_a enthalpy of air and fuel before combustion, Btu per pound of original air

H_g enthalpy of burned gases at exit-gas temperature, Btu per pound of original air

h lower heating value of fuel, 18,500, Btu per pound

f/a fuel-air ratio

For the purpose of these calculations, H_g was assumed equal to the enthalpy of air at the exhaust-gas temperature plus the sum of the enthalpies of carbon dioxide and water that results from complete combustion minus the enthalpy of oxygen required for complete combustion. Enthalpy values were obtained from reference 2.

Attempts were also made to determine the combustion efficiency by measuring the carbon-dioxide and oxygen content of the exhaust gases. The combustion efficiencies obtained by this method were considerably higher than the results obtained from the pressure and the gas-flow measurements. Calculations involving the heat-transfer process between the water-cooled sampling tube and the exhaust gases indicate that this discrepancy existed because the exhaust gases were in the sampling tube an appreciable length of time before being cooled sufficiently to stop combustion.

RESULTS AND DISCUSSION

At the highest combustion-chamber inlet velocity attainable with the blower (200 ft/sec without combustion), ignition took place at a fuel-air ratio of approximately 0.020. The engine operated without excessive noise or vibration for the entire range of operating conditions and at no time did the flame advance upstream of the flame holder.

The exhaust flame consisted of a short, steady blue flame extending approximately 1 foot beyond the exit of the engine for a fuel-air-ratio range of 0.045 to 0.065. As the fuel-air ratio was increased above stoichiometric (0.067), the exhaust flame became longer and yellow due to afterburning of the excess fuel. The horizontal gutters of the flame holder failed to hold the flame properly at fuel-air ratios from 0.055 to 0.045. Below a fuel-air ratio of 0.045, the flame was held solely by the vertical gutters of the flame holder and became increasingly irregular and unsteady with a decrease in fuel-air ratio until the lean blow-out limit was reached. The irregular burning in the combustion chamber is believed to result from the inadequate penetration of the fuel particles into the air stream because of the low fuel pressures that exist at the low fuel-flow rates. This inadequate penetration of the fuel particles created zones of fuel-air mixtures sufficiently rich to maintain localized combustion. Because of this unstable condition, the exact fuel-air ratio at which blow-out occurred was difficult to measure.

During operation at fuel-air ratios of 0.060 and higher, short red streaks appeared on the wall of the combustion chamber directly behind each flame-holder support. These supports held the flame at the higher fuel-air ratios and caused combustion to occur near the wall.

The general effect of fuel-air ratio on combustion efficiency is shown in figure 3. The maximum combustion efficiency obtained was 84 percent at a fuel-air ratio of 0.063 and a combustion-chamber inlet velocity of 83 feet per second. The average combustion efficiency was 80 percent at fuel-air ratios from 0.060 to 0.068 over a range of combustion-chamber inlet velocities from 64 to 83 feet per second. In general, a change in fuel-air ratio above or below stoichiometric mixture (0.067) resulted in a decrease in combustion efficiency. The rapid decrease in combustion efficiency with decreasing fuel-air ratio between a fuel-air ratio of 0.055 and 0.045 was due in part to the gradual blow-out of the flame at the horizontal gutters. The inlet-air temperature varied from 90° to 130° F and the ambient-air pressure from 28.90 to 29.25 inches of mercury. These small variations apparently had little effect on combustion efficiency. Because of the fixed-area fuel nozzles, the other variables such as fuel pressure and temperature were a function of fuel-air ratio and inlet-air velocity at the flame holder.

The effect of a variation in combustion-chamber inlet velocity on combustion efficiency for four constant fuel-air ratios is shown in figure 4. At fuel-air ratios of approximately 0.065 and 0.055, no noticeable change in combustion efficiency occurred for the variation in combustion-chamber inlet velocity. At fuel-air ratios of approximately 0.043 and 0.033, an increase in combustion-chamber inlet velocity resulted in an increase in combustion efficiency.

The effect of fuel-air ratio on gas total-temperature rise is presented in figure 5. A temperature rise of approximately 3000° F was obtained at stoichiometric fuel-air ratio. Slightly higher temperature rises were obtained at fuel-air ratios from 0.070 to 0.080.

Fuel-air-ratio distribution across the exit of the ram-jet engine determined by oxidized exhaust-gas analyses is shown in figure 6 for calculated fuel-air ratios of 0.065 and 0.042. In general, the fuel-air ratio is slightly richer through the horizontal center line than near the walls of the chamber. The average fuel-air ratio obtained by Orsat analysis was in close agreement with the calculated fuel-air ratio.

SUMMARY OF RESULTS

From a test-stand investigation of a rectangular ram-jet engine over a range of fuel-air ratios from 0.025 to 0.083 and combustion-chamber inlet velocities from 61 to 124 feet per second, the following results were obtained:

1. At the highest combustion-chamber inlet velocity attainable with the blower (200 ft/sec without combustion), ignition took place at a fuel-air ratio of approximately 0.020.

2. The engine operated without excessive noise or vibration for the entire range of operating conditions.

3. The combustion efficiency was approximately 80 percent at fuel-air ratios from 0.060 to 0.068 over a range of combustion-chamber inlet velocities from 64 to 83 feet per second. In general, a change in fuel-air ratio above or below stoichiometric mixture resulted in a decrease in combustion efficiency.

4. The only noticeable effect of combustion-chamber inlet velocity on combustion efficiency occurred at fuel-air ratios less than 0.043, at which condition an increase in combustion-chamber inlet velocity resulted in an increase in combustion efficiency for a given fuel-air ratio.

5. Exhaust-gas analysis indicated fairly uniform fuel-air-ratio distribution across the exit of the ram jet for fuel-air ratios of 0.065 and 0.042.

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REFERENCES

1. Perchonok, Eugene, Wilcox, Fred A., and Sterbentz, William H.: Preliminary Development and Performance Investigation of a 20-Inch Steady-Flow Ram Jet. NACA ACR No. E6D05, 1946.

2. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN No. 1086, 1946.

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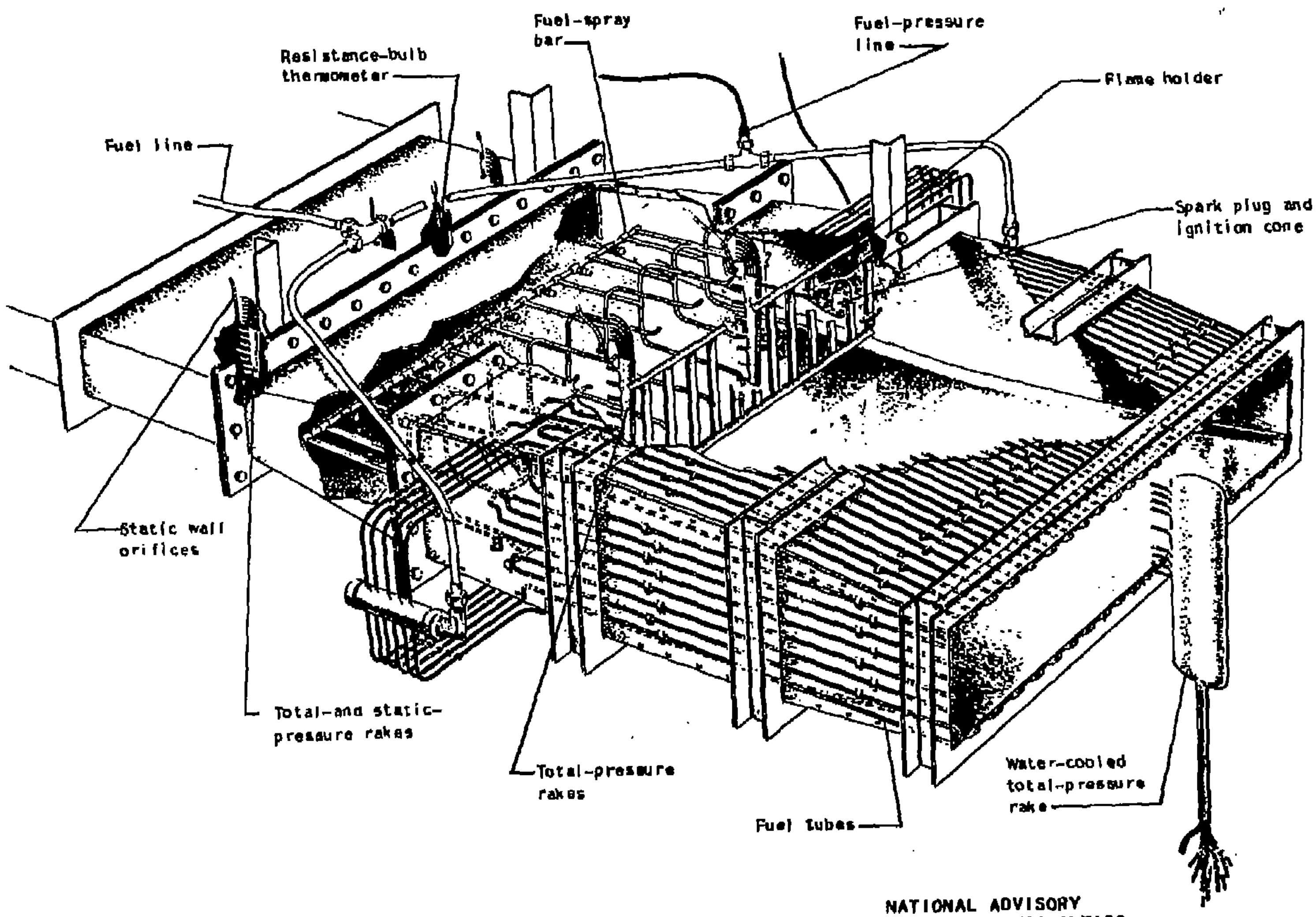

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Figure 1. - Rectangular ram-jet engine.

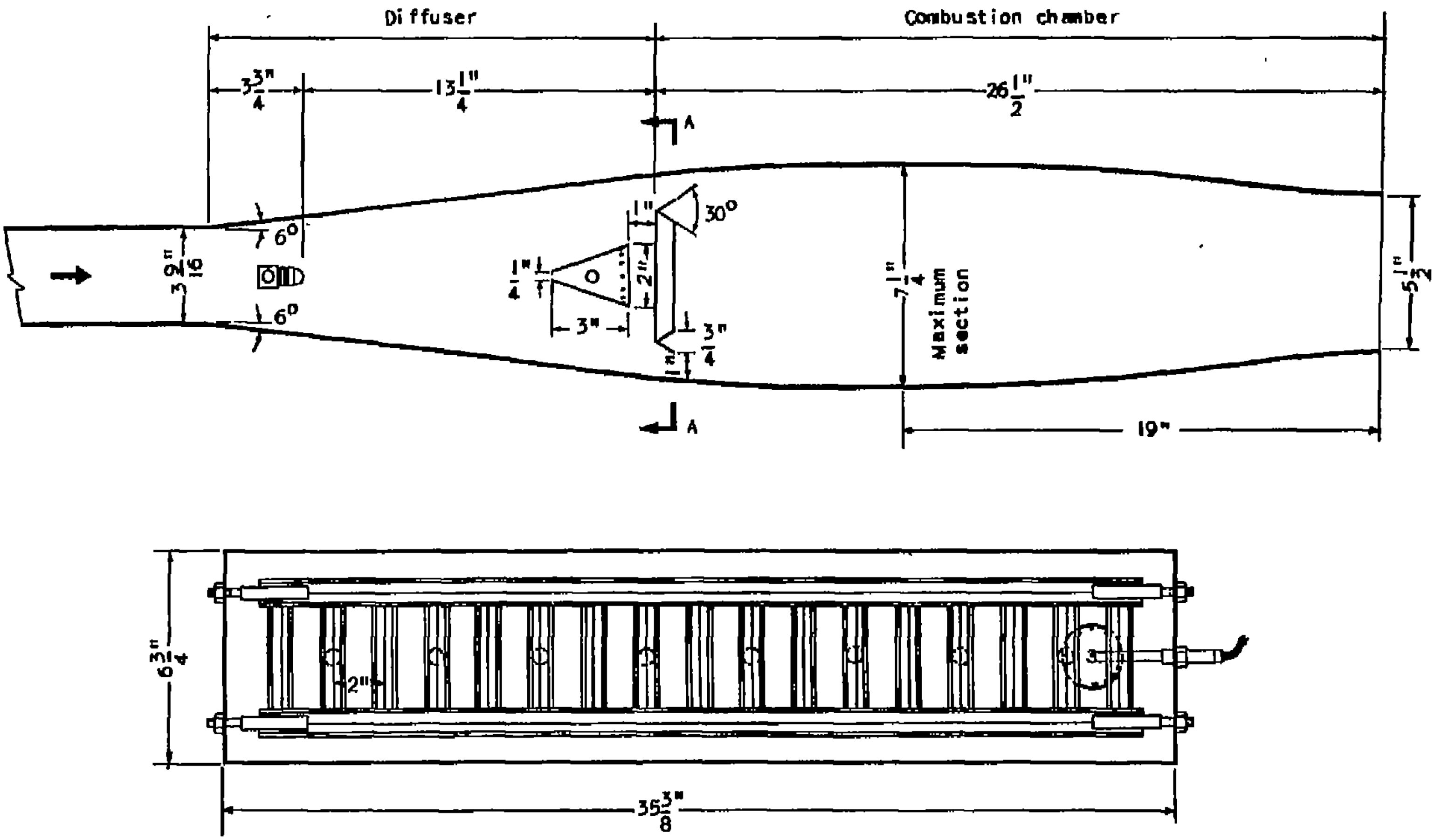

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Figure 2. – Schematic drawing of rectangular ram-jet engine.

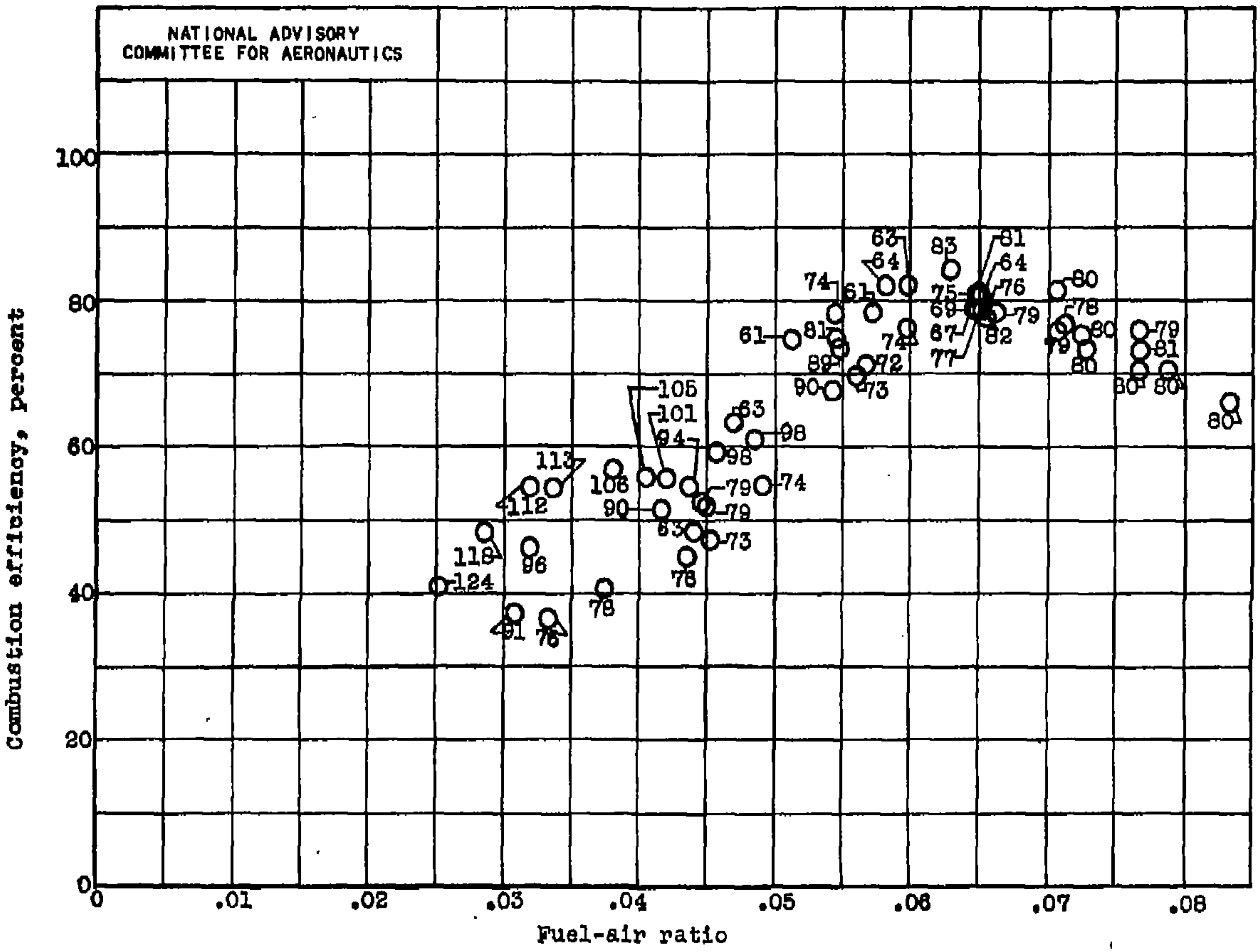


Figure 3. - Effect of fuel-air ratio on combustion efficiency for rectangular ram-jet engine. (Numbers refer to combustion-chamber inlet velocities, ft/sec.)

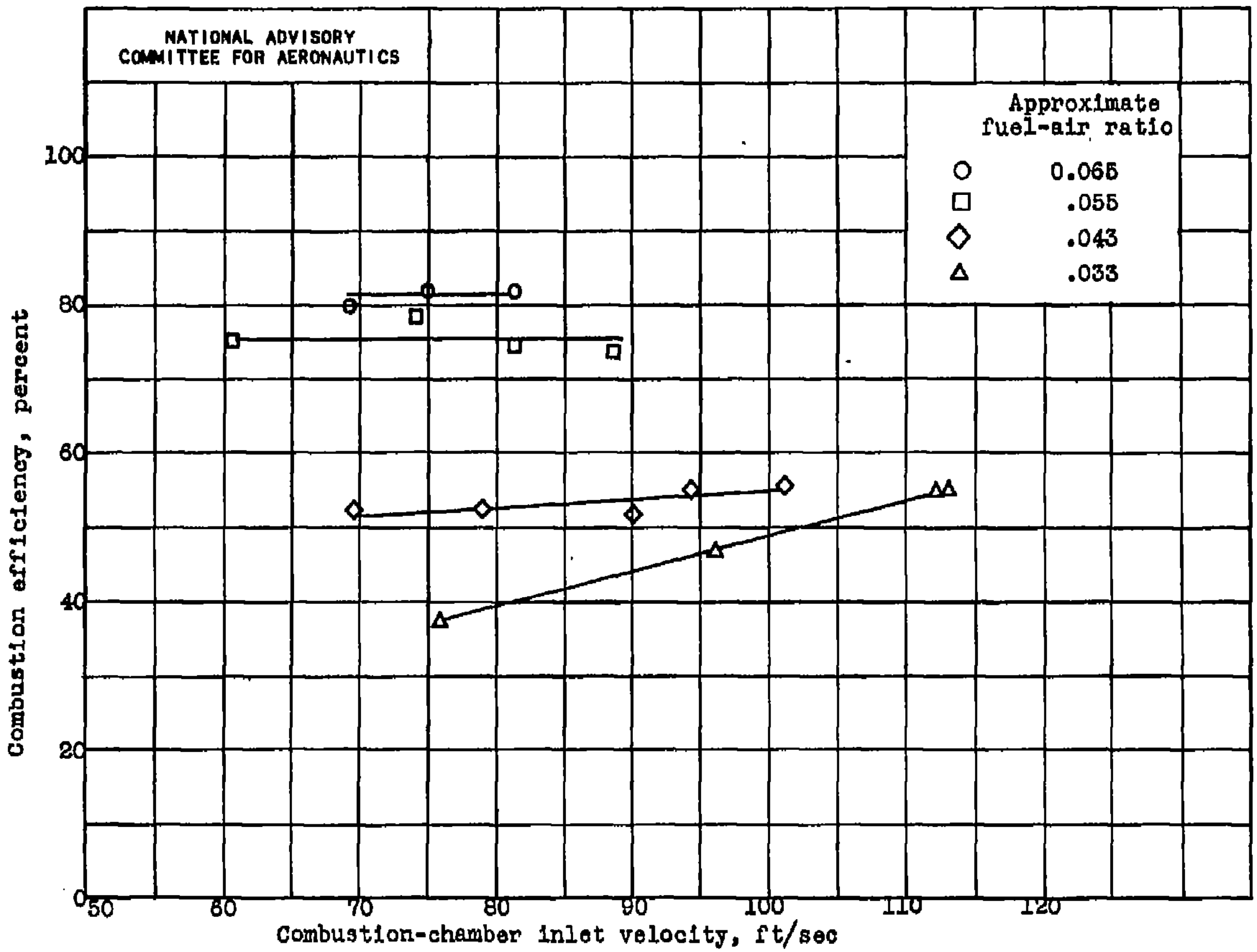


Figure 4. - Effect of combustion-chamber inlet velocity on combustion efficiency for rectangular ram-jet engine at constant fuel-air ratios.

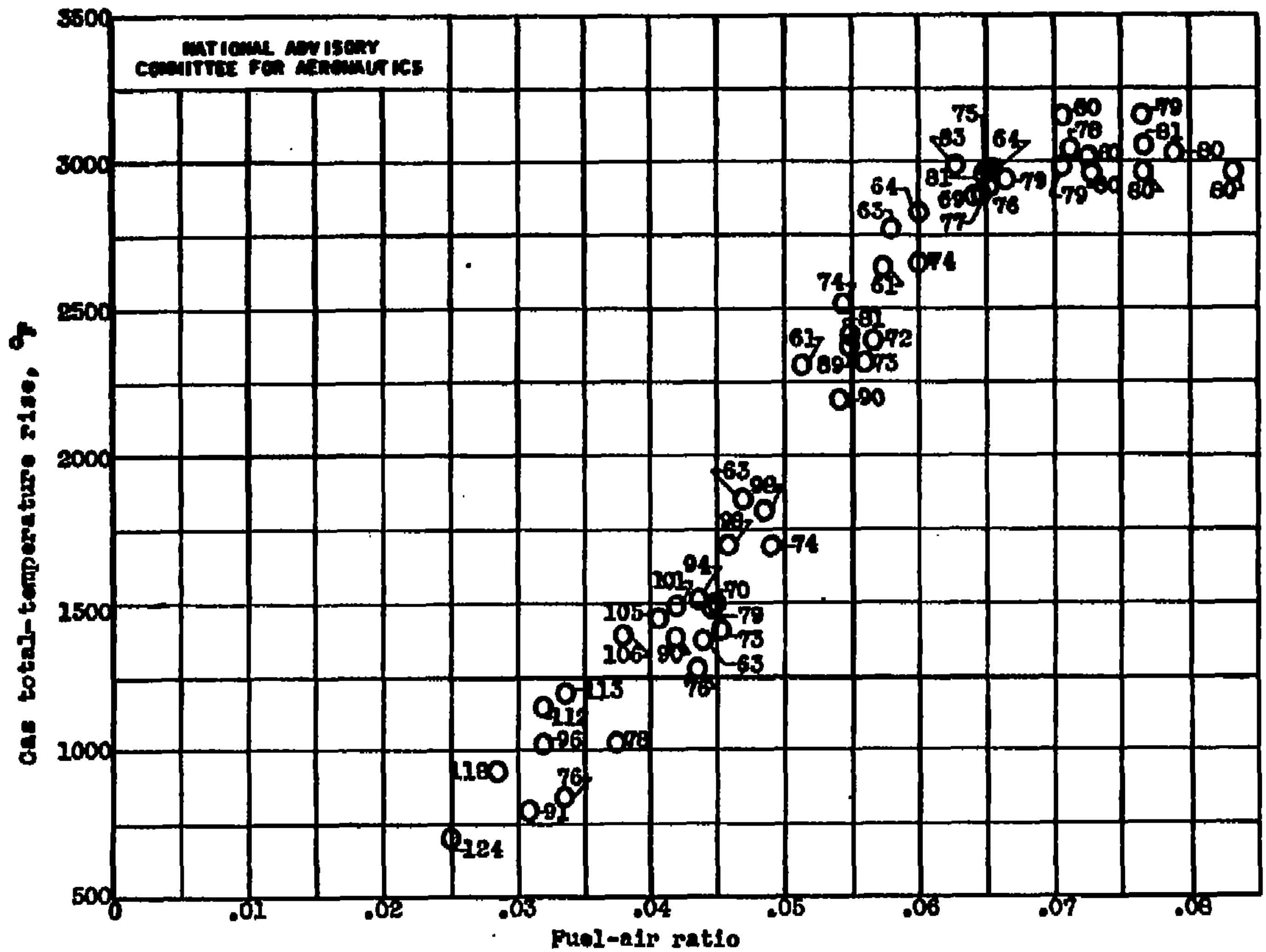
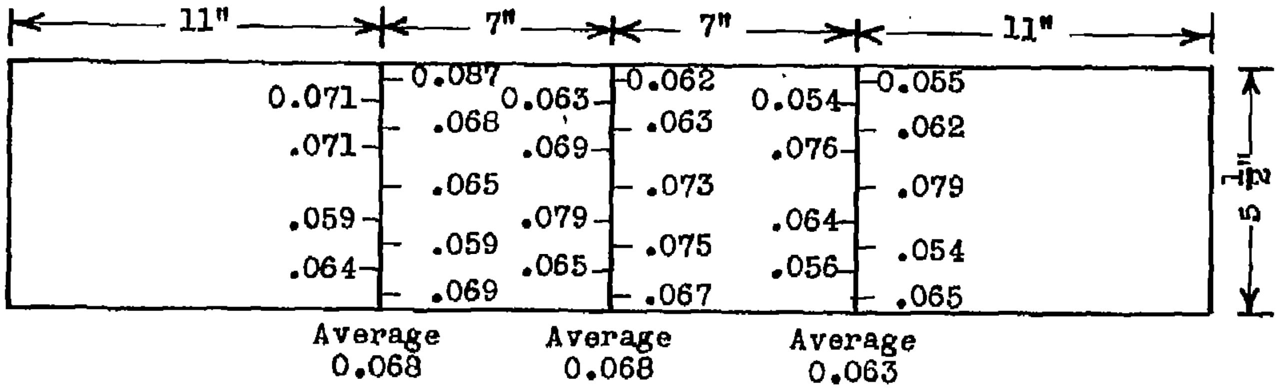
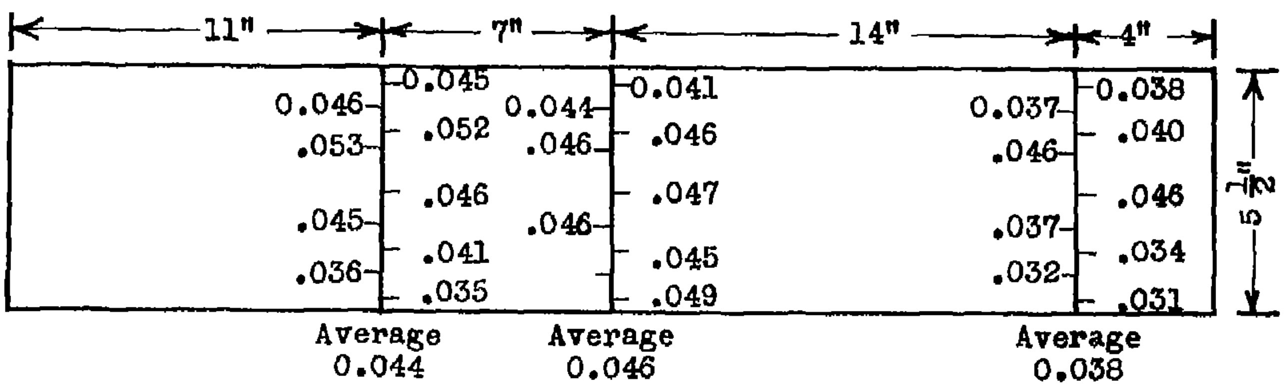


Figure 5. - Effect of fuel-air ratio on gas total-temperature rise for rectangular ram-jet engine. Average inlet-air temperature, 100° F. (Numbers refer to combustion-chamber inlet velocities, ft/sec.)



(a) Fuel-air ratio, 0.065, as calculated from fuel-flow and air-flow measurements.



(b) Fuel-air ratio, 0.042, as calculated from fuel-flow and air-flow measurements.

Figure 6. - Fuel-air-ratio distribution determined by Orsat analysis of exhaust gases at various stations across exit of rectangular ram-jet engine.